CHAPTER TWO

Diodes

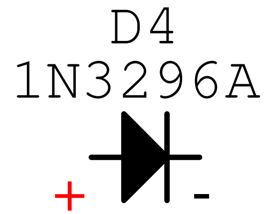
Digital Electronics.

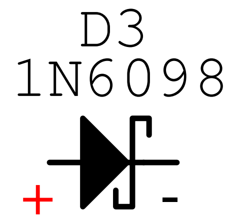
Introduction

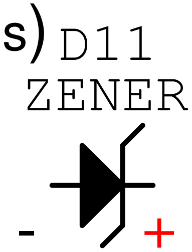
Ch 2

Barrier

- Types of diodes:
  - PN-junction (p-type & n-type)
  - Schottky (metal & n-type) (*MN diodes*) (but not all metals)
  - Zener (P^+N^+-junction)







- Applications of diodes:
  - Variable capacitors
  - DC voltage level-shifting (faster switching speed)

Diode Modelling

- Schockly's current-voltage characteristics:

$$I_D = I_S\left(\exp\left\{\frac{V_D}{\phi_T}\right\}-1\right)$$

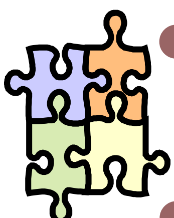
Thermal voltage : =25.9mV @ 300K

$$\phi_T = \frac{kT}{q}$$

T → Temerature [K]

q → Elementary charge=1.6x10^{-19} [C]

k → Boltzmann's constant=1.38x10^{-23} [J/K]



- Example

Using Schockly's expression, determine the diode current for V_D=0.1, 0.2, 0.5, 0.7, 0.8,1, 1.1; assuming I_S=10^{-14} A.

- Solution

$I_D(V_D=0.1)$=465 fA

$I_D(V_D=0.2)$=22.6 pA

$I_D(V_D=0.5\ )$=2.42 μA

$I_D(V_D=0.7\ )$=5.47 mA

$I_D(V_D=1.1)$=27.9 kA

$I_D(V_D=0.8\ )$=260 mA

f, p, n, μ, m
-15, -12, -9, -6, -3

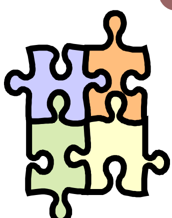
!Diode become damaged

Practical for IC devices

- Schockly's current-voltage characteristics:

$$I_D = I_S\left(\exp\left\{\frac{V_D}{\phi_T}\right\}-1\right)$$

- Example



Using Schockly's expression, determine the diode current for V_D=-0.1, -0.2, -0.5, -0.8,-1, assuming $I_S=10^{-14}$ A.

- Solution

$I_D(V_D=-0.1)=-0.979\ I_S$

$I_D(V_D=-0.2)=-0.99956\ I_S$

$I_D(V_D=-0.5)=-0.999999996\ I_S$

$$\boxed{I_D(V_D \geq 0.1) \approx I_S\left(e^{\frac{V_D}{\phi_T}}\right)}$$

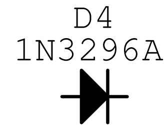
$$\boxed{I_D(V_D \leq -0.1) \approx -I_S}$$

Diode Modelling

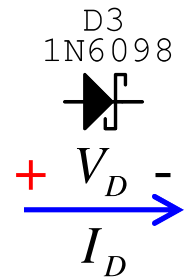
Ch 2

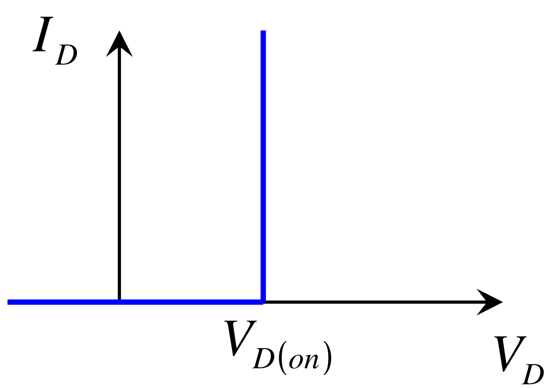
- Piecewise linear model:
  - Cutoff: $I_D = 0$ for $V_D < V_{D(on)}$
  - Conducting: $V_D = V_{D(on)}$ for $I_D > 0$

$V_{D(on)} = 0.7\,V$



$V_{D(on)} = 0.3\,V$





- Skip sections <u>2.3 & 2.4</u>

Diode-Resistor Logic

© Dr. Anas

Ch 2

- Consists only of diodes and resistors
- Performs AND and OR logic functions

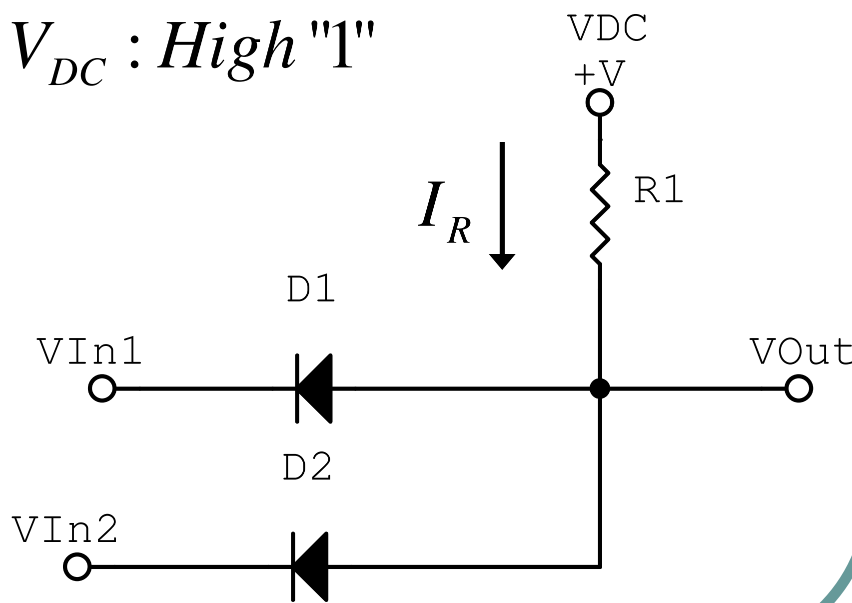
1. Diode AND gate

For $V_{in(1,2)} > V_{DC} - V_{D(ON)} \Rightarrow D_{(1,2)}$ is "OFF"

$$V_{in(1\&2)} : High\ "1" \Rightarrow V_{Out} = V_{DC} : High\ "1"$$

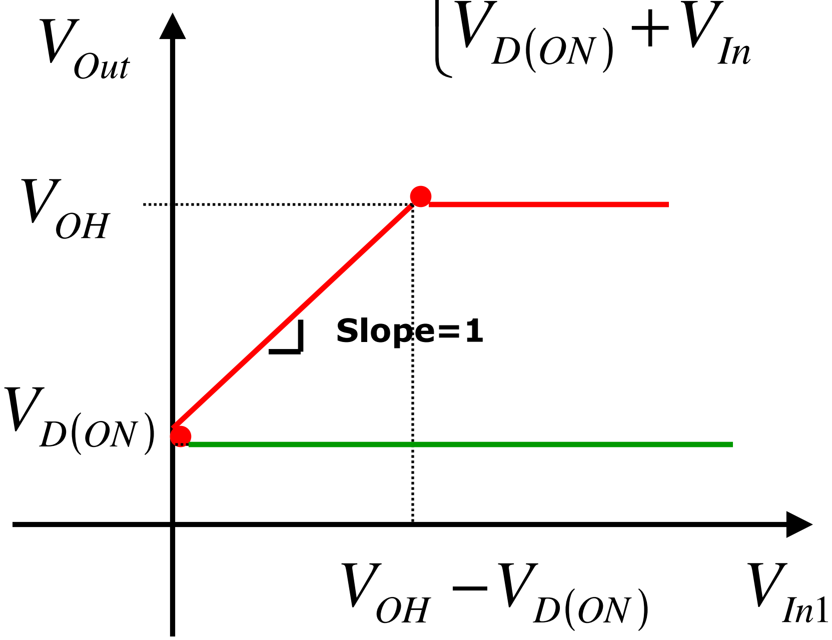
$$I_R = \begin{cases} 0; \\ \text{when } \underline{\text{both}}\ \text{D}_1 \text{ and D}_2 \text{ are } OFF \\ \left(V_{DC} - V_{D_{ON}} - V_{In}\right)/R_1; \\ \text{when } \underline{\text{either}}\ \text{D}_1 \text{ or D}_2 \text{ is } ON \end{cases}$$

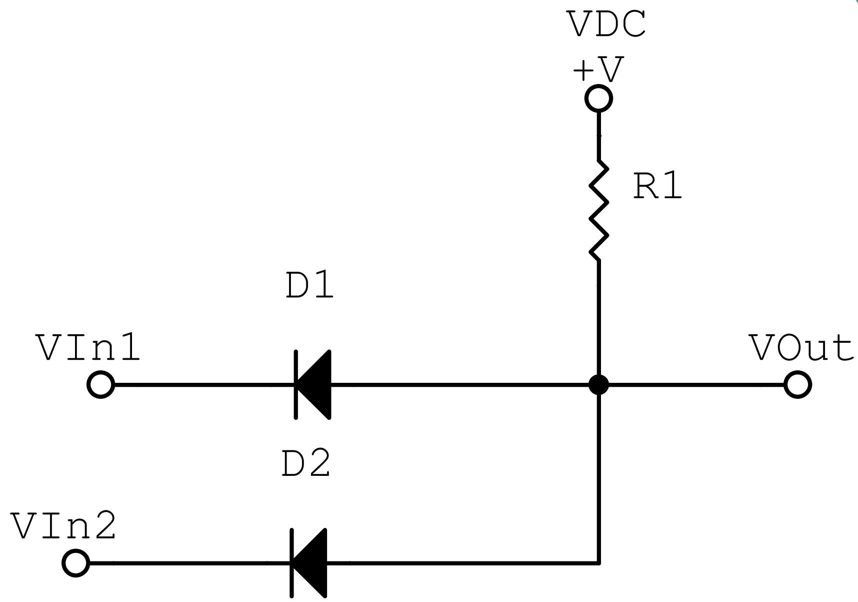
V1	V2	Vo
L	L	L
L	H	L
H	L	L
H	H	H



1. Diode AND gate

$$V_{Out} = \begin{cases} V_{DC} = V_{OH} \\ or \\ V_{D(ON)} + V_{In} \end{cases}$$





V_{In2} is high

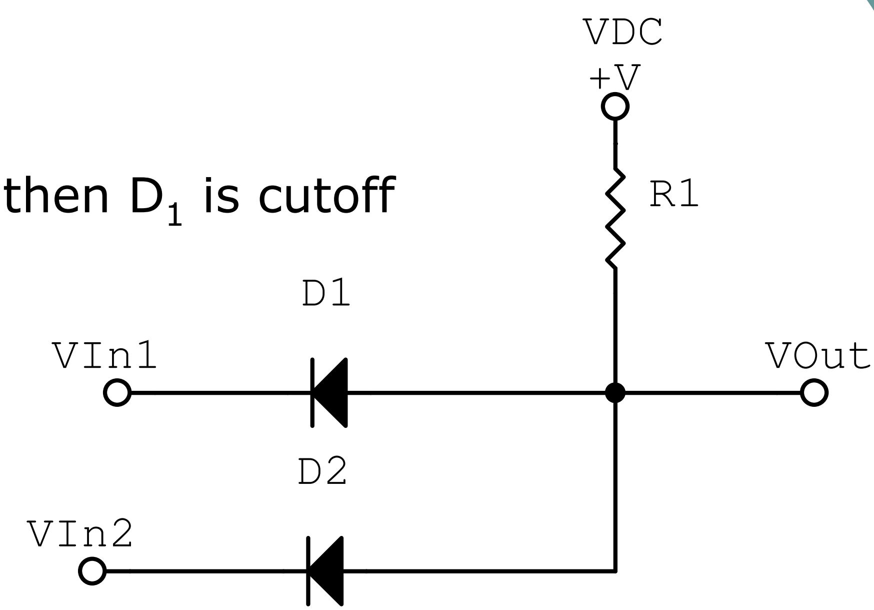
V_{In2} is low $= 0V$

Diode-Resistor Logic

Ch 2

- Example

Show that if $V_{In1} \geq V_{In2} + 1$, then D_1 is cutoff



- Solution

$$V_{Out1} = V_{D1} + V_{In1}$$
$$\geq V_{D1} + V_{In2} + 1$$
$$V_{Out2} = V_{D2} + V_{In2}$$

$$\boxed{\begin{aligned} V_{Out2} &= V_{Out1} \\ V_{D2} + V_{In2} &\geq V_{D1} + V_{In2} + 1 \end{aligned}}$$

$$\boxed{V_{D2} \geq V_{D1} + 1}$$

If $V_{D1} = V_{D(on)} \rightarrow V_{D2} \geq 1.7V$

Max. Of V_{D1} and V_{D2} is $V_{D(on)}$ is 0.7V.

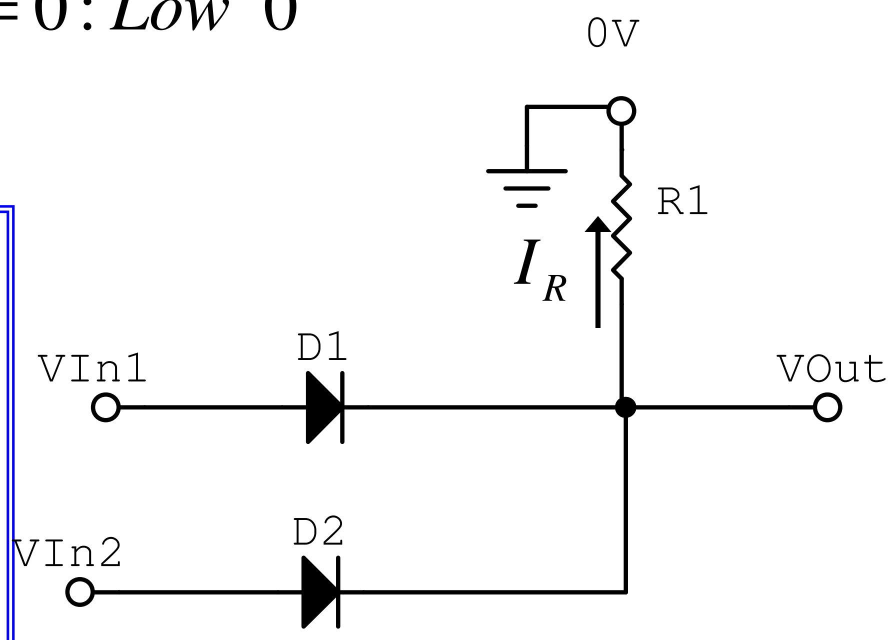
V_{D1} has to be $-0.3V \leq V_{D(on)}$

Ch 2

2. Diode OR gate

For $V_{in(1,2)} > V_{D(ON)} \Rightarrow D_{(1,2)}$ is "ON"

$V_{in(1\&2)} : Low\ "0" \Rightarrow V_{Out} = 0 : Low\ "0"$



$$I_R = \begin{cases} 0; & \text{when } \underline{\text{both}}\ D_1 \text{ and } D_2 \text{ are } OFF \\ \left(V_{In} - V_{D_{ON}}\right) / R_1; & \text{when } \underline{\text{either}}\ D_1 \text{ or } D_2 \text{ is } ON \end{cases}$$

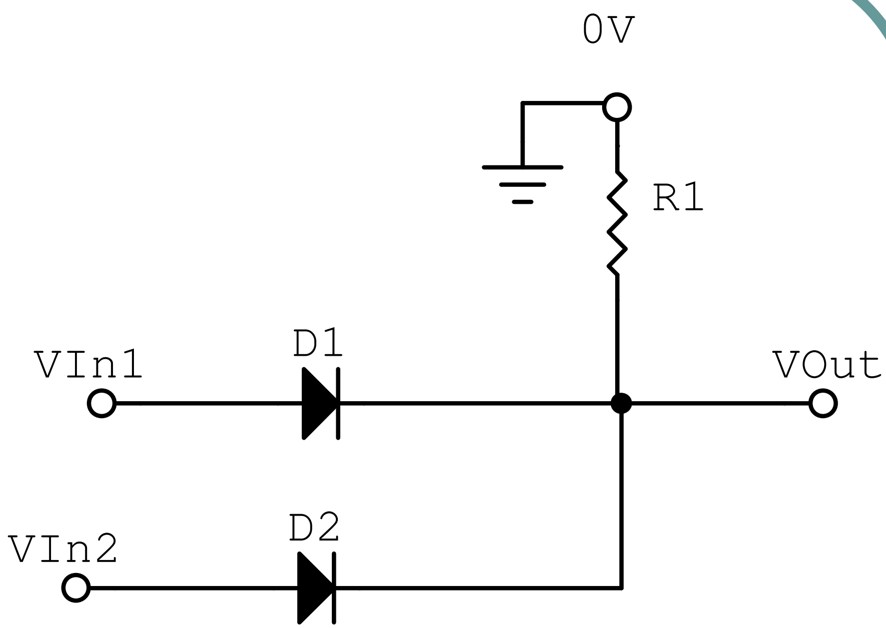
V1	V2	Vo
L	L	L
L	H	H
H	L	H
H	H	H

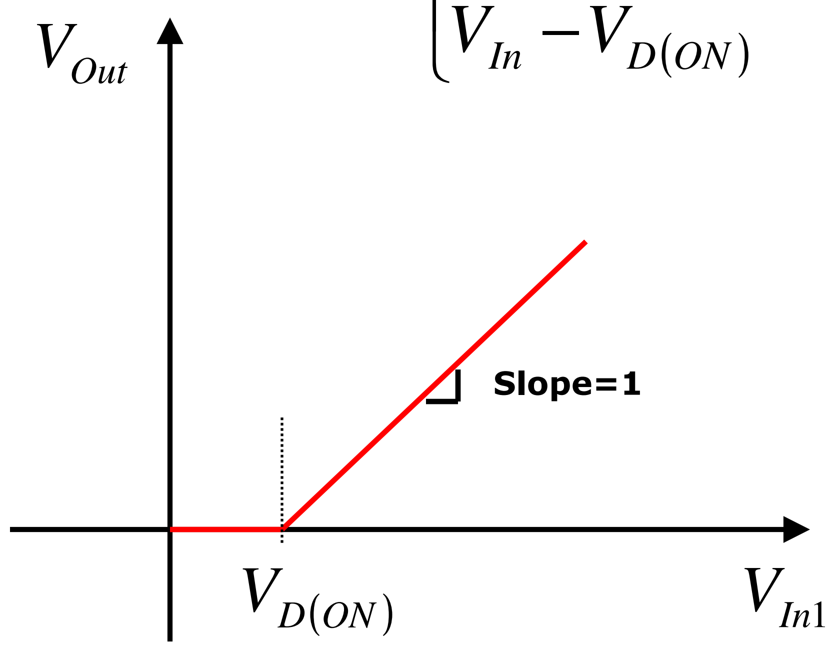
Diode-Resistor Logic

Ch 2

2. Diode OR gate

$$V_{Out} = \begin{cases} 0 = V_{OL} \\ or \\ V_{In} - V_{D(ON)} \end{cases}$$





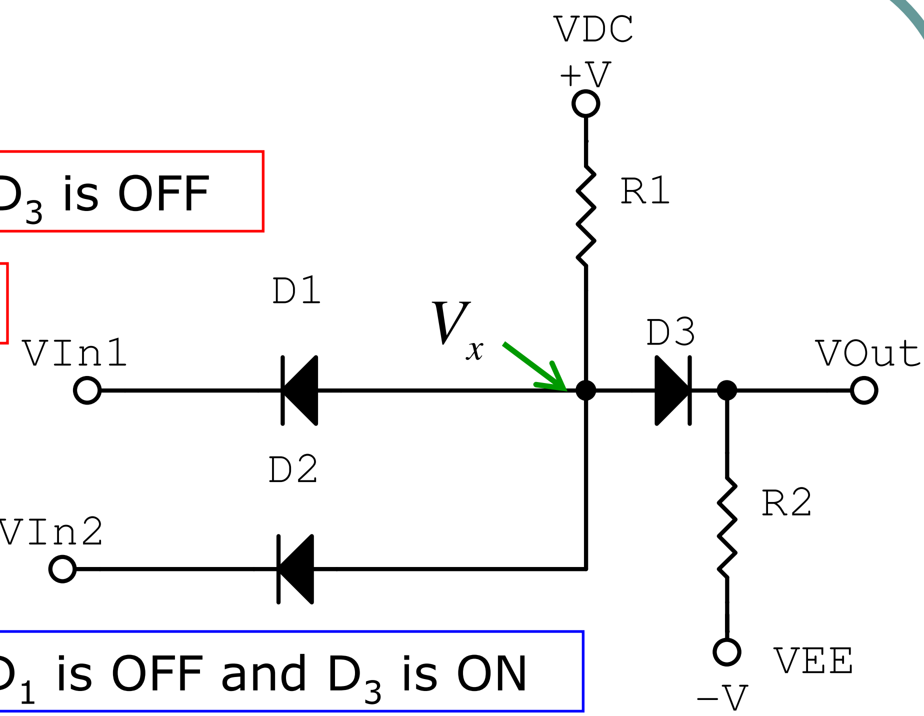
$\boxed{V_{In2} \text{ is low}}$

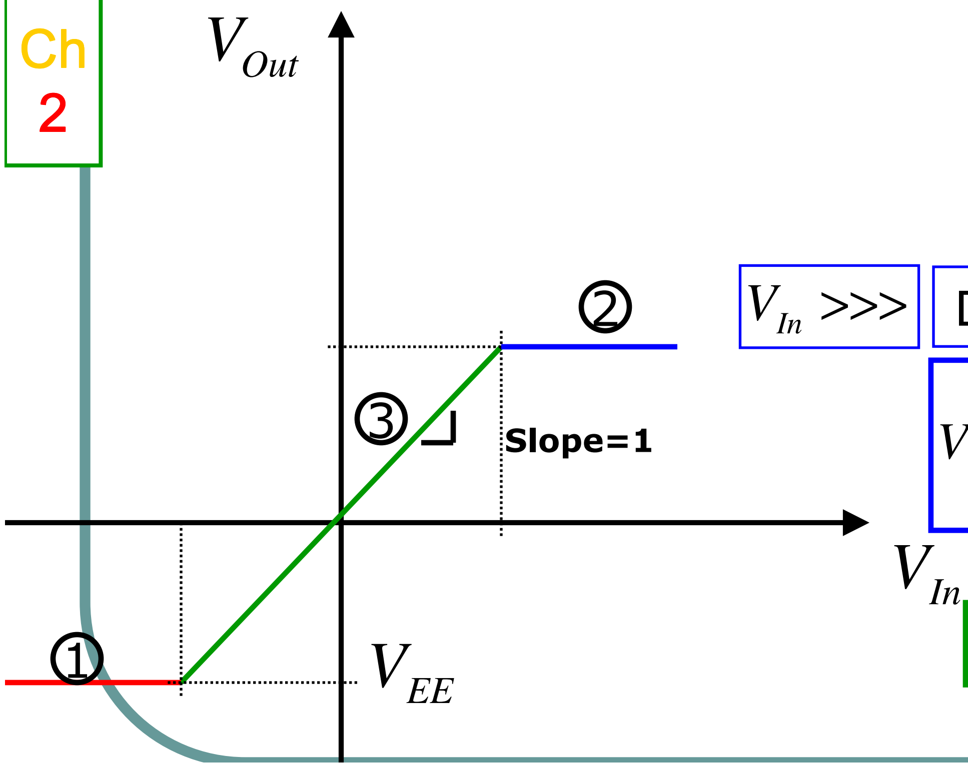
Level Shifted AND Gate

To plot the VTC:

$V_{In} <<<$ D$_1$ is ON and D$_3$ is OFF

$V_{Out} = V_{EE}$ (-ve value)





$V_{In} >>>$ D$_1$ is OFF and D$_3$ is ON

$$V_{Out} = V_{EE} + R_2\left(\frac{V_{DC} - V_{EE} - V_{D(ON)}}{R_1 + R_2}\right)$$

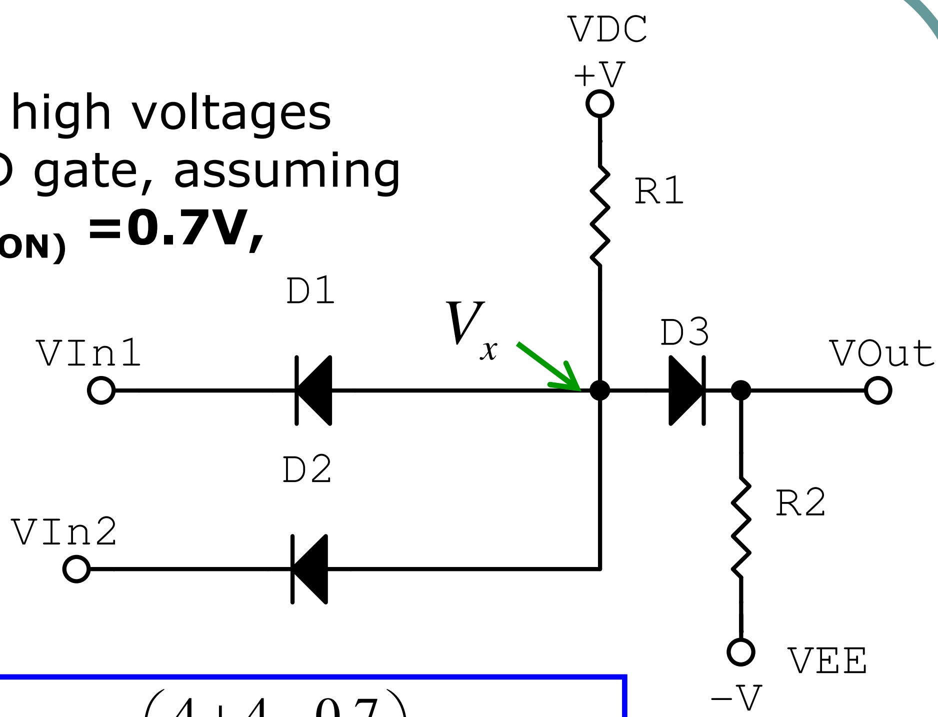
In between $V_{out} = V_{in}$

Ch 2

Level Shifted AND Gate

- **Example**

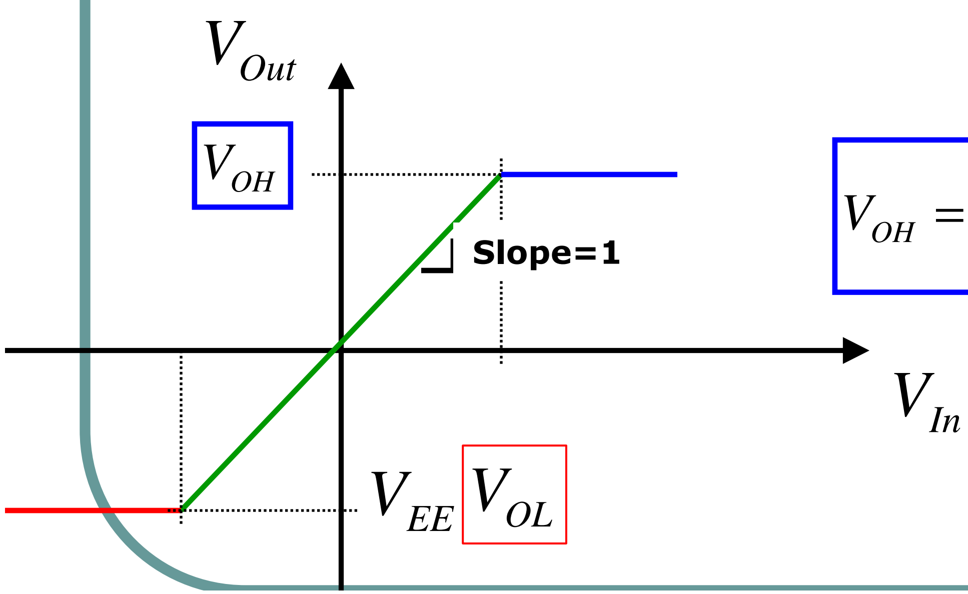
Find the output low and high voltages for the level-shifted AND gate, assuming **V_{DC}=4V, V_{EE}=-4V, $V_{D(ON)}$ =0.7V, R_1=1kΩ, R_2=2kΩ.**



- **Solution**

$$\boxed{V_{OL} = V_{EE} = -4V}$$

$$\boxed{V_{OH} = -4 + 2\left(\frac{4+4-0.7}{3}\right) = 0.867V}$$



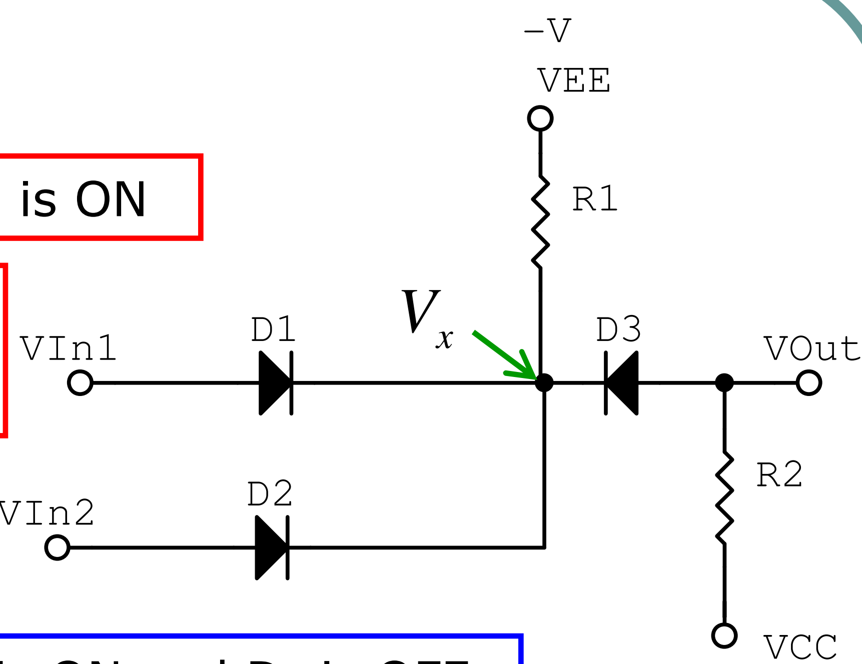
Level Shifted OR Gate

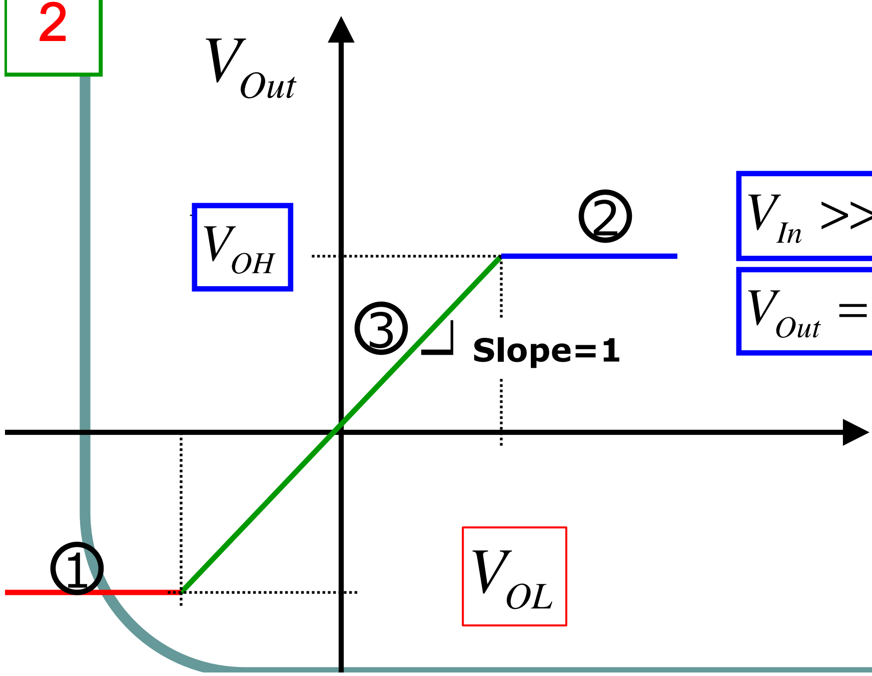
Ch 2

To plot the VTC:

$V_{In} <<<$ — D_1 is OFF and D_3 is ON

$$V_{Out} = -R_2\left(\frac{V_{CC} - V_{EE} - V_{D(ON)}}{R_1 + R_2}\right) + V_{CC}$$





$V_{In} >>>$ — D_1 is ON and D_3 is OFF

$V_{Out} = V_{CC}$ — Such that $V_x > V_{CC} - V_{D(ON)}$

$V_{in} > V_x + V_{D(ON)}$

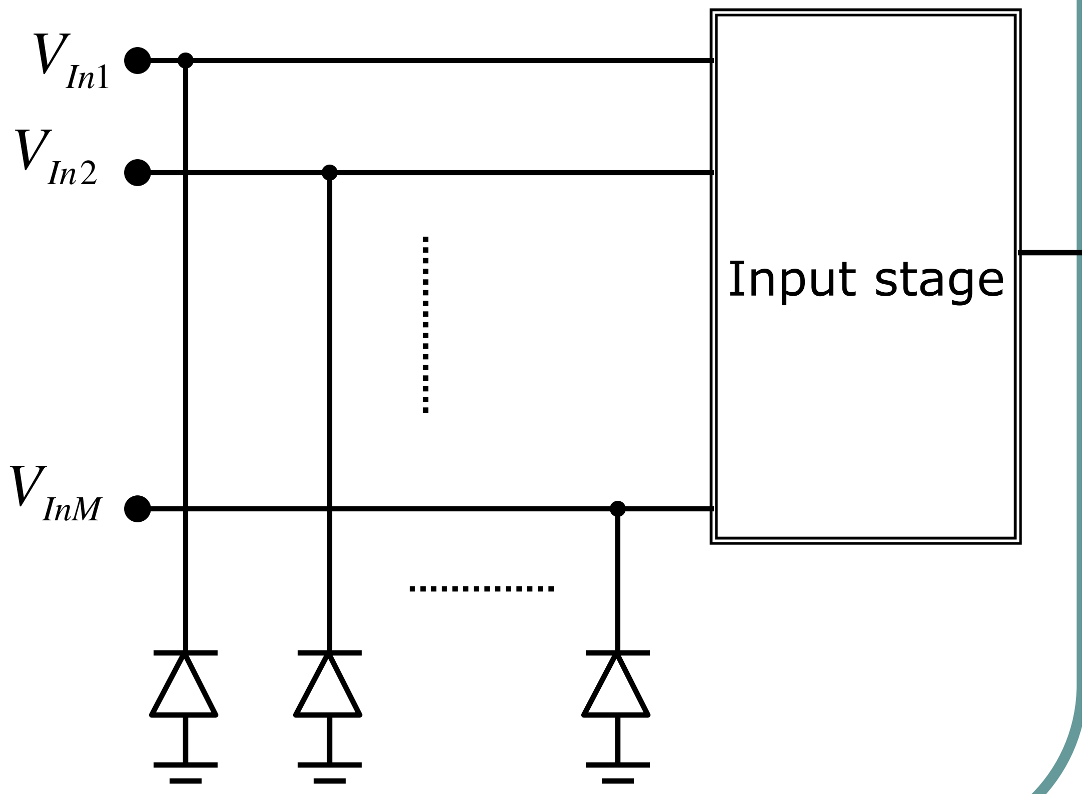
In between $V_{out} = V_{in}$

Clamping Diodes (other applications)

- Some gates may get damaged when their input voltages are negative

- The diodes prevent the inputs from falling below $-V_{D(ON)}$

- When the input voltages are positives, those diodes are open circuits



Level Shifting Diodes (other applications)

- Easy , and also stated before

- HW #2:Solve Problems: 2.6, 2.8, 2.12 , 2.18, 2.20, 2.21